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Devitalization of Weed and Cereal Seeds by a Radio Frequency Generator

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DEVITALIZATION OF WEED AND CEREAL SEEDS BY A

RADIO FREQUENCY GENERATOR

By

Dwight W. Lambert

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INTRODUCTION

Weed control work has gone forward throughout the nation during this post war period. The work has not only been in the herbicidal field but also in the field of cleaning and processing of crop seed to be used for planting purposes. At the present time the soil of our country contains considerable weed seed without more being added through unclean crop seed. Norris (2) has shown that there were as many as 90 weed seeds in 37.8 square inches of soil to a depth of 6 inches that germinated during a single year. When calculated on an acre basis this amounted to 14,974,830 weed seeds that germinated in one year on a single acre. In addition many more viable seeds were still lying in the soil awaiting the right conditions to germinate. In a check of 124 seed samples of cereal grains received for purity at the South Dakota State College Agronomy Seed Laboratory, it was found that there were an average of 611 weed seeds in each pound of cereal grain. This amount of weed seed added to that already shown to be in the soil definitely does not indicate good weed control.

Devitalization of weed seed by placing the seed in a Radio Frequency Field was considered as one possible means of reducing the weed seed population in seed, feed and farm grain. In previous work by the Electrical Engineering Department of South Dakota State College it was known that the Radio Frequency Generator was capable of producing enough heat or energy to explode popcorn in a short period of time. With this thought in mind, an attempt was to be made to inactivate or devitalize weed seed found in grain or crop seeds. Another objective was to determine if there is a difference between the amount or length of exposure to radio frequency waves required to destroy the viability of the weed seed, and the amount needed to destroy the germination of the crop seed. This work was done during 1948 and 1949 with the cooperation of the Electrical Engineering Division of South Dakota State College.

REVIEW OF LITERATURE

The use of heat as a means of inactivating seeds has been reported by Caldecott and Smith (1). Inactivation was obtained by subjecting barley and einkorn to 70 and 75 degrees C., respectively, for 30 minutes. Using year old barley seed enclosed in a sealed glass capsule, Peto (3) placed it in a drying oven at 95 degrees C. A slight decrease in germination was observed at 15 minutes and further heating induced reduction in germination until at 35 minutes the seed had lost its viability.

Peto (3) reports that a very high chromosomal mutation rate in barley was induced by heat treatments of seed under various conditions of humidity. Two lots of seed were treated at 95 degrees C. for 25 minutes. One lot of seminal root tips were taken from germinating seeds within a day or two after germination had commenced. The other lot was taken from plants 40 days after seeding. The first lot showed 68 percent mutants as to 20 percent for the second lot. The reduction in mutants in the second lot indicates that there must be an elimination of mutant cells during the development of the plant. Chromosomal mutants observed in the barley at 95 degrees C. consisted almost entirely of fragments. Indications are that fracture occurred quite frequently at the exact point where the kinetic constriction (attachment constriction) is located. Sax and Enzmann (5) state that the frequency of chromosome aberration is increased by high temperature or by X-ray in their work on Tradescantia microspores.

Smith (6) using variation in age, heat and X-ray in his work on polyploidy of wheat, found that polyploids were more tolerant to X-ray than heat. Polyploids will withstand more heat and X-ray than related diploid, all other things being equal.

No published work was found on devitalization of seed by means of a Radio Frequency Generator.

MATERIAL AND METHODS

Equipment for this investigation was furnished by the Electrical Engineering Department and the Agronomy Seed Laboratory of South Dakota State College. All devitalization tests were made in the engineering building using a Westinghouse radio frequency generator set to operate on a frequency of 15 megacycles. The generator operated on 115 volts 60 cycles and had a maximum output of one kilowatt. It was of the single tube type using tube #883A. Dielectric heating was used, which is the thorough and uniform heating of a non-conducting material when the material is placed in an electric field of high frequency. The heat is generated by the high frequency currents set up in the sample between the electrodes. For a view of this generator and the method used in treating the seed see Figures 1 & 2.

Germination tests were made in the Agronomy Seed Laboratory with the use of the standard germinators, paper towels and blotters. Except in the number of seed used in a germination test, the materials and methods used in germinating the seeds were those prescribed by the Association of Official Seed Analysts (4). For most grain and weed seeds tests, 2-100 seed samples were used. With field bindweed, however, 2-50 seed samples were used for the germination tests. These changes were necessitated by the limited quantity of weed seed available for use in the tests.

Mida spring wheat, Clinton oats, and Feebar barley were the grain varieties used. Only well matured high germinating lots of these varieties were selected for the experimental work.

Seed which was well developed and readily available of seven noxious weeds was used as follows: Perennial Peppergrass, _Lepidium_ _draba_ L.; Canada Thistle, _Circium_ _arvense_ (L.) Scop.; Field Bindweed, _Convolvulus_ _arvensis_ L.; Wild Mustard, _Brassica_ _arvensis_ Ktze; Wild Oats, _Avena_ _fatua_ L.; Quackgrass, _Agropyron_ _repens_ (L.) Beauv. and Leafy Spurge, _Euphorbia_ _esula_ (L.) Hill.

Fig. 1. Radio frequency generator used in devitalizing seeds.

Fig. 2. A close up of the radio frequency generator showing the electrodes used for treating the seed sample.

Germination tests were made on the weed seeds in order to determine the amount of dormancy that might be encountered. Preliminary trials were made in an effort to overcome dormancy conditions and to obtain a satisfactory germination of seed from wild oats, field bindweed, perennial peppergrass, wild mustard, and leafy spurge. It was found that complete germination could be obtained from the hard seeds of field bindweed by chipping a small portion of the seed coat opposite the embryo. In wild mustard it was found that by moistening the substratum with a .2 percent solution of potassium nitrate, germination could be increased by approximately 50 percent. This treatment, however, still failed to break completely the dormancy. In wild oats it was found that by subjecting the seed to some scarification (breaking the glumes surrounding the caryopsis) some of the dormancy could be broken and the germination thus increased. No methods of increasing the germination of perennial peppergrass and leafy spurge were found in the limited trials studied.

The amount of plate voltage needed and the time required at a particular voltage to produce lethality, required much time and preliminary experimentation. As a result of preliminary tests the frequency was raised from 10 to 15 megacycles. This increase seemed to produce the necessary amount of power required to devitalize seed. To determine the lethal range for killing seed, a series of tests using different plate voltages and various periods of time were set up. The range in plate voltage varied from 1500 to 3000 and in time from 2 to 5 minutes. In the preliminary test, wheat was mixed with the weed seeds of wild oats, leafy spurge, Canada thistle, perennial peppergrass and wild mustard.

Preparing samples for testing

Sufficient material was prepared at one time so that eight tests could be made, one test for each of the plate voltages at a specific treatment time limit.

The weed seeds were kept separate until ready to run in the generator and then mixed with the cereals. As 200 weed seeds of each kind were to be used in each of the germination test, 250 seeds of each kind to be tested were placed in the sample. The weed seeds were prepared by placing them in an air blast separator which blew out all light and immature seed. The weed seeds then were picked over for inert material and any other impurities. Only sound, well developed weed seeds were selected for the tests since maximum germination of the weed seeds was desired.

Seed of wheat, oats and barley was placed in a container in equal amounts to act as carrier for all eight tests. The seeds were thoroughly mixed by pouring several times through a mechanical divider.

Running the Test in the Radio Frequency Generator

Samples were treated at eight different plate voltages. These different plate voltage adjustments were run for each of four different time lengths. Plate voltages used were: 1500, 1700, 1900, 2100, 2300, 2500, 2700, and 2900. The time lengths used were two, three, four, and five minutes.

A clear plastic tube 3 1/4 inches in diameter and 2 3/4 inches high was used for holding the seed between the two electrodes on top of the generator. These electrodes were 6 inches in diameter. The distance between these electrodes could be regulated so that they were the height of the plastic tube.

The operation of the generator consisted of (1) placing the tube on top of the lower electrode, (2) filling the plastic tube with the seed, (3) Adjusting the top electrode directly over the tube and lower electrode, (4) turning on the power, and (5) adjusting the plate voltage on the generator tube to the desired value. A stop watch was used for the timing of the duration of the treatment. At the beginning of the treatment, readings were made of all four meters which recorded plate voltage, grid current, plate current, and radio frequency current through the sample. This was done for each test. At the completion of each test, the sample was placed in an envelope on which was recorded the meter readings and the length of time in the generator.

Germination Procedure

After treatment, samples were taken to the seed laboratory. The mixed samples were divided into separate groups each containing only one field grain or one kind of weed seed. After separation, 2-100 seed samples were counted of each kind of cereal and weed seed from each treatment. Wheat, oats, barley, and wild oats were placed between paper towels, which were moistened with tap water, wrapped in wax paper and placed in germinators set at 17 degrees C. After a period of 10 to 12 days germination counts were made. All other seeds except wild mustard, were placed on or between standard germinating blotters which were moistened with tap water and placed in the alternating germinator set at 30 degrees C. daytime (8:30 a.m. to 4:30 p.m.) and 20 degrees at night (4:30 p.m. to 8:30 a.m.). Wild mustard seeds were placed on blotters in petri dishes which were moistened with the potassium nitrate solution. The mustard seeds were then placed in the alternating germinator. A preliminary count was made, usually after 7 days on all seed placed in the alternating germinator. The final reading was made at the end of 21 days.

Because of the hard seed coat, germination at the end of 14 days was always low in field bindweed so each hard seed of bindweed was scarified. Before scarification all normal sprouts and dead seeds were counted and removed from the blotters. Scarification was accomplished by holding each individual seed with a forceps and with a knife blade a very small portion of the outer seed coat was chipped off of the end opposite from the embryo. This seed was then placed back in the germinator and the final germination count was made 7 days later.

Potential Gradient

The potential gradient of the field in which the sample was placed for treatment was used as the basis for comparing these tests. The potential gradient is measured in volts per inch of distance between the electrodes. As 8 different samples were run for a time period, each at a different plate voltage, 8 potential gradient readings were obtained during one time period.

To calculate the potential gradient the following formulas were used:

(1) $C = \frac{EA}{T}$

Where C = the capacitance in farads
E = Permittivity of air (8.855×10^{-12})
A = Area of one electrode in square meters
T = Distance between electrodes in meters.

(2) $X_c = \frac{1}{2\pi FC}$

Where X_c = Capacitive reactance in ohms
F = Frequency in cycles per second
π = 3.1416

(3) Potential Gradient (volts per inch) = $\frac{X_c \ I_{RF}}{T'}$

Where I_{RF} = The radio frequency current in amperes.(obtained from the radio frequency ammeter during each test)
T' = Distance between electrodes in inches.

As the plate voltages have been used in describing the results in the experiment, Table 1. is set up so that reference to it may be made to find the potential gradient to which the sample was subjected.

Table 1. Potential gradients for each of the eight different voltages at four different time periods.

Time Period	*Potential Gradients							
	** Plate voltage							
	1500	1700	1900	2100	2300	2500	2700	2900
2 - minute	2100	2100	2600	3000	3100	3500	3800	3800
3 - minute	1900	2400	2400	2800	2900	3200	3500	3800
4 - minute	1700	1900	2300	2200	2400	2700	2900	3000
5 - minute	1700	2500	2900	2600	2900	2700	2900	3000

* Potential gradient, volts/inch between electrodes.
** Plate voltage, voltage on plate of generator tube.

EXPERIMENTAL RESULTS

The germination results have been summarized in four tables to show the amount of inactivation of the three cereal and seven weed seeds used in the treatment tests. Each table reports the germination of all species used in the tests at one time period and eight plate voltages. By showing the germination results in this form, it is possible to see whether there is a difference in the germination between the cereal and weed seed at any one treatment.

Table 2 shows the germination of seed when exposed for two minutes at different plate voltages of the generator.

Table 2. Average germination of the three cereal and seven weed seeds when exposed two minutes to treatment by a radio frequency generator set at eight different plate voltages.

Cereals and weeds	Percent of germination								
*Pot.grad.	2100	2100	2600	3000	3100	3500	3800	3800	
**P.voltage	1500	1700	1900	2100	2300	2500	2700	2900	Untreated
Wheat	86	87	92	84	88	61	10	3	87
Oats	97	93	95	90	95	94	18	6	96
Barley	93	97	92	94	90	89	16	4	96
Wild oats	73	63	71	63	61	61	22	15	83
Field bindweed	76	81	81	74	75	80	3	1	66
P.peppergrass	33	24	30	33	36	17	0	1	33
Leafy spurge	16	17	22	23	13	9	1	3	25
Wild mustard	24	35	28	32	39	21	2	3	22
Canada thistle	42	51	56	26	41	24	0	1	41
Quackgrass	90	90	77	80	79	81	17	9	88

* Potential gradient, volts/inch between electrodes.
** Plate voltage, voltage on plate of generator tube.

Little effect on the germination of seed was produced until 2500 or more plate volts were applied. A voltage of 2500 caused a noticeable reduction in the germination of wheat, perennial peppergrass, wild mustard, and Canada thistle. At 2700 volts there was a marked decrease in germination of seed of all species in the test with complete devitalization obtained in perennial peppergrass and Canada thistle. Field bindweed, leafy spurge, and wild mustard at 2700 volts had a germination of three, one and two percent respectively, which is very close to devitalization. With the exception of wild oats and quackgrass, all the germinations at 2900 volts were six percent or lower. At 2900 volts perennial peppergrass, field bindweed and Canada thistle germinated one percent. Leafy spurge and wild mustard germinated three percent, quackgrass germinated nine percent but wild oats still had a germination of 15 percent. Little difference was seen between the germination of the cereal and weed seeds.

Table 3. shows the germination of seed when exposed for three minutes at different plate voltages of the generator.

Table 3. Average germination of the three cereal and seven weed seeds when exposed three minutes to treatment by a radio frequency generator set at eight different plate voltages.

Cereals and weeds	Percent of germination								
	*Pot.grad. 1900	2400	2400	2800	2900	3200	3500	3800	
	**P.voltage 1500	1700	1900	2100	2300	2500	2700	2900	Untreated
Wheat	94	93	78	96	88	66	15	28	94
Oats	97	98	85	95	92	92	21	17	98
Barley	93	91	75	96	87	78	18	16	95
Wild oats	73	71	81	65	86	83	53	50	73
Field bindweed	79	80	59	87	58	78	18	21	83
P.peppergrass	19	15	7	22	22	10	1	2	25
Leafy spurge	23	20	7	20	15	9	1	1	19
Wild mustard	13	22	15	28	25	22	4	4	10
Canada thistle	40	47	9	48	13	8	1	1	44
Quackgrass	75	73	60	77	75	69	22	23	80

* Potential gradient, volts/inch between electrodes
** Plate voltage, voltage on plate of generator tube

The germinations at the three minute time period are similar to the two minute time period, with little effect on germination of the seed until 2500 plate volts were applied. A decrease in germination at 2500 volts is shown for wheat, perennial peppergrass, leafy spurge, and Canada thistle. At 2700 volts a marked decrease is shown in all species. Perennial peppergrass, leafy spurge, and Canada thistle germinated one percent. There was little change in the germinations between the 2700 and 2900 volt treatments.

No explanation can be given for the reduced germinations at 1900 volts which were not obtained at 2100 and 2300 volts. The potential gradient, which is measured in volts per inch between electrodes, is the same at 1700 and 1900 volts but not as high as at 2100 volts where the germination corresponded with the germination obtained at the 1700 volts treatment.

Table 4. shows the germination of seed when exposed for four minutes at different plate voltages of the generator.

Table 4. Average germination of the three cereal and seven weed seeds when exposed four minutes to treatment by a radio frequency generator set at eight different plate voltages.

Cereals and weeds	Percent of germination								
*Pot.grad.	1700	1900	2300	2200	2400	2700	2900	3000	
**P.voltage	1500	1700	1900	2100	2300	2500	2700	2900	Untreated
Wheat	97	97	99	94	63	26	5	1	96
Oats	99	99	99	97	88	50	8	2	97
Barley	97	98	99	96	69	32	2	0	98
Wild oats	76	75	82	75	83	54	5	2	74
Field bindweed	77	88	83	69	24	13	4	0	71
P.peppergrass	30	34	34	31	13	2	2	1	42
Leafy spurge	22	19	27	17	10	4	1	0	25
Wild mustard	39	40	45	54	31	13	6	0	50
Canada thistle	38	37	36	32	11	1	0	0	53
Quackgrass	90	92	88	91	70	23	6	1	85

* Potential gradient, volts/inch between electrodes
** Plate voltage, voltage on plate of generator tube

No reduction in germination at the four minute time period was obtained for all species at the treatments of 1500, 1700, and 1900 plate volts. At 2100 volts, with the exception of wild mustard and quackgrass, all species showed a decline in germination. This was followed with a marked decrease in germination, except for wild oats, of all species at 2300 volts. 2500 and 2700 volts gave decreases in the germination of all species, with perennial peppergrass, leafy spurge and Canada thistle being reduced to two, four and one percent, respectively. The highest germination obtained at 2700 volts was eight percent in oats and the lowest germination was zero percent for Canada thistle.

Devitalization was approached at 2900 plate volts where a zero percent germination was obtained on barley, field bindweed, leafy spurge, wild mustard, and Canada thistle. Oats and wild oats had germination readings of two percent at 2900 volts and wheat, perennial peppergrass, and quackgrass had readings of one percent.

Canada thistle showed a continued drop in germination from 1500 plate volts, the first plate voltage used, until devitalization was obtained at the 2700 and 2900 voltages. Beginning at 1500 volts with 200 volt steps to 2900 volts the germination readings on Canada thistle are 38, 37, 36, 32, 11, 1, 0 and 0 percent respectively.

Table 5 shows the germination of the seed when exposed for five minutes at different plate voltages of the generator.

Table 5. Average germination of the three cereal and seven weed seeds when exposed five minutes to treatment by a radio frequency generator set at eight different plate voltages.

Cereals and weeds	Percent of germination								
	*Pot.grad. 1700	2500	2900	2600	2900	2700	2900	3000	
	**P.voltage 1500	1700	1900	2100	2300	2500	2700	2900	Untreated
Wheat	97	94	92	63	24	1	0	0	96
Oats	97	97	96	86	38	1	0	0	97
Barley	95	97	89	67	33	0	0	0	98
Wild oats	77	75	80	88	75	4	1	1	74
Field bindweed	60	58	50	39	26	1	0	0	71
P.peppergrass	40	34	28	9	1	1	0	0	42
Leafy spurge	20	21	15	6	2	1	0	0	25
Wild mustard	39	43	48	25	22	0	0	0	50
Canada thistle	24	34	21	6	2	0	0	0	53
Quackgrass	77	88	90	69	42	3	0	0	85

* Potential gradient, volts/inch between electrodes.
** Plate voltage, voltage on plate of generator tube.

Germination of the seed at the five minute time period in table 5 gave uniform and consistant results; that is, every increase in plate voltage was accompanied by a decrease in germination. Wheat germinated 97 percent at 1500 volts and with successive increases of 200 volts to 2900 volts the respective germinations were; 94, 92, 63, 24, 1, 0, and 0 percent. Field bindweed and perennial peppergrass had the same trend as wheat. The same was observed in the case of the other cereals and weed seeds but the decrease started at a higher voltage. At the five minute time period, a decrease in germination of all seeds except wild oats, was noted at 2100 volts with a marked decreased at 2300 volts. At 2500 volts germinations were very low, four percent being the highest and this with wild oats. Barley, wild mustard and Canada thistle showed germination of zero at 2500 volts. Except for the one percent germination of wild oats no viable seeds were found in either the 2700 or 2900 volt treatments.

Illustrations are given on pages 14 and 15 of field bindweed and quackgrass to show the trend of devitalization at the five minute time period. Figures 3 and 6 are checks or untreated samples of field bindweed and quackgrass, respectively and show normal germination. Figures 4 and 7 show reduction in germination at 2300 plate volts for field bindweed and 2500 volts for quackgrass. In figures 5 and 8 devitalization is shown of both field bindweed and quackgrass. These illustrations were taken after nine days of germination for quackgrass and six days of germination, after scarification, for field bindweed.

Results of each Cereal or Weed Illustrated Graphically

Further illustration of the action of the radio frequency generator on the germination of the cereal and weed seeds is presented in figures 9 to 18. Each figure is a graph pertaining to one species, either cereal or weed, which was treated at the four time periods. These time periods are plotted against eight different plate voltages. The voltages begin at 1500 volts and with 200 volt increases continue through 2900 volts. Each graph shows the percent of germination of a given species treated at the eight voltages and four time periods.

With wheat, oats, barley, wild oats, field bindweed and quackgrass where a high germination was obtained, the germination results were plotted on graphs with a range of zero to 100 percent. Wild mustard, perennial peppergrass, leafy spurge and Canada thistle rarely exceeded 50 percent germination and were plotted on graphs with a germination range of zero to 50 percent.

Figure 9 illustrates the action of eight different plate voltages and four different time periods on the germination of wheat.

Fig. 3. The germination of untreated field bindweed seed 6 days after scarification.

Fig. 4. The germination of field bindweed seed, 6 days after scarification, treated at 2300 plate volts for 5 minutes.

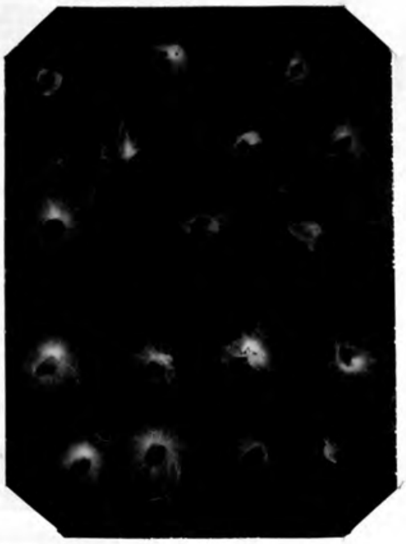

Fig. 5. The germination of field bindweed seed, 6 days after scarification, treated at 2900 plate volts for 5 minutes.

Fig. 6. The germination of untreated quackgrass seed at the end of 9 days.

Fig. 7. The germination of quackgrass seed at the end of 9 days, treated at 2500 plate volts for 5 minutes.

Fig. 8. The germination of quackgrass seed at the end of 9 days, treated at 2900 plate volts for 5 minutes.

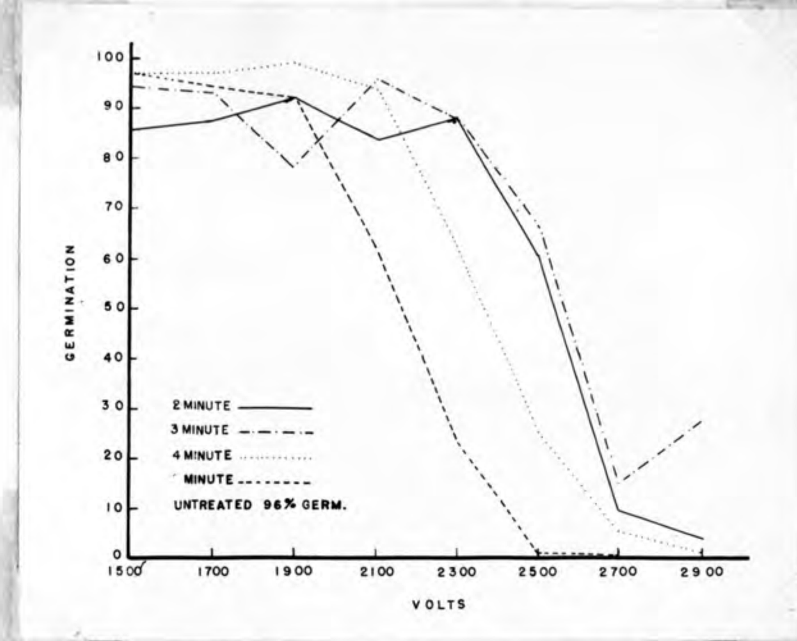

Fig. 9. The germination of wheat shown at eight different radio frequency plate voltages and for four different time periods.

During the two and three minute time periods, the germinations were variable as indicated by the curves on the graph. This variability continued until 2300 plate volts at two minutes and 2100 volts at three minutes. After these voltages there was a gradual decrease in germination. The four and five minute time periods show less variable germinations. The germinations at the four minute time period started to decrease at 2100 volts. The germination at the five minute time period showed a decrease from 1500 volts until devitalization at 2700 volts.

In figure 10 the germination of oats is plotted against eight different plate voltages for four different time periods.

Oats had a greater resistance to time and plate voltage treatments than did wheat. With the two and three minute time periods, the germinations did not decrease until 2500 volts were applied. A large decrease was obtained with 2700 volts. At the four minute time period, no effect on germination was noted until 2100 volts were applied. A noticeable decrease in germination occurred at 2300 volts. The sharp decreases in germination were obtained

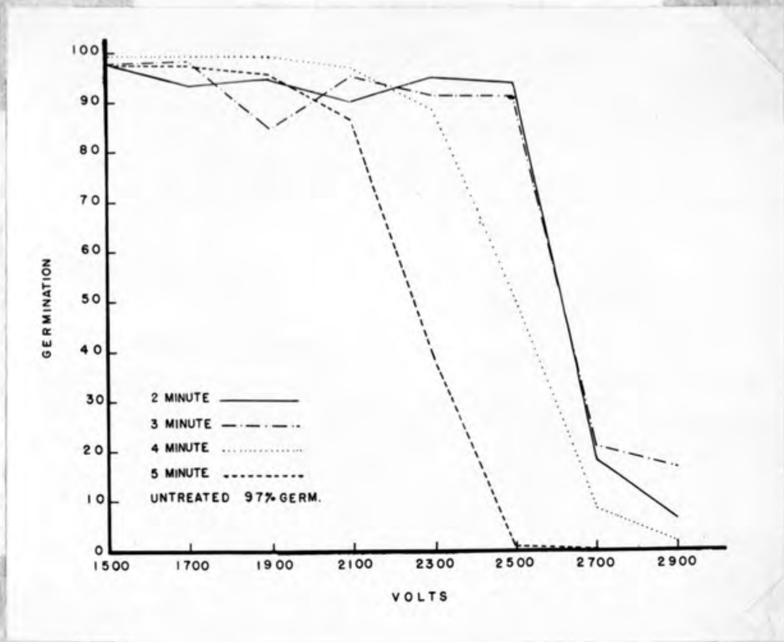

Fig. 10. The germination of oats shown at eight different radio frequency plate voltages and for four different time periods.

at 2500 and 2700 volts. The five minute time period germination decreased after 1700 volts and devitalization was obtained at 2700 volts.

Figure 11 illustrates the action of eight different plate voltages and four different time periods on the germination of barley.

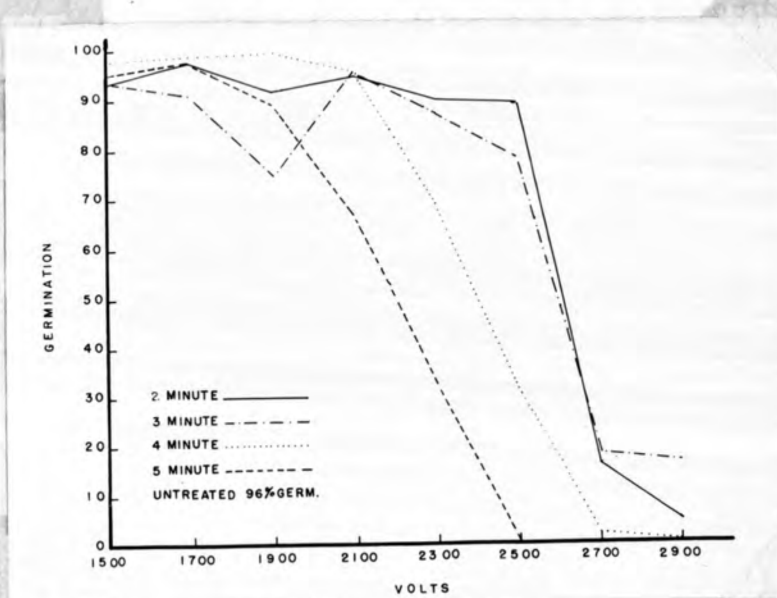

Fig. 11. The germination of barley shown at eight different radio frequency plate voltages and for four different time periods.

During the two minute time period, a uniform germination is shown up to 2500 plate volts with a large decrease at 2700 volts. At the three minute time period, the germination started to decrease after 2100 volts. At the four minute time period, the germination started to decrease at 1900 volts and continued to decrease until devitalization occurred at 2900 volts. Germinations started to decrease at 1700 volts at the five minute time period and continued to decrease until devitalization occurred at 2500 volts.

The germination of wild oats is shown in figure 12 at eight different plate voltages and for four different time periods.

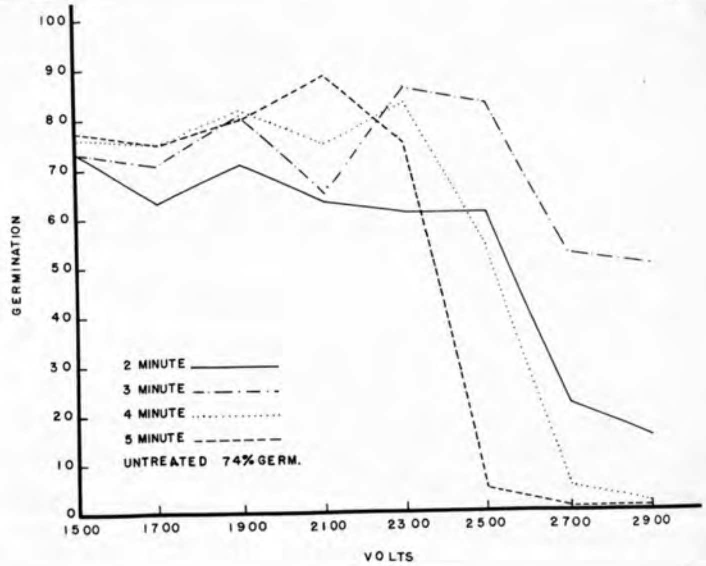

Fig. 12. The germination of wild oats shown at eight different radio frequency plate voltages and for four different time periods.

At the two minute time period a decrease in germination begins at 1900 plate volts with a large drop in germination at 2500 volts. At the three minute time period the germination was very erratic, with a germination of 73 percent at 1500 volts and 71, 81, 65, 86, 83, 53, and 50 percent germination at the respective voltages following 1500 volts. The four minute time period germinations decrease from 83 percent at 2300 volts to 5 percent at 2700 volts. The germination at 2900 volts was two percent. At the five minute time period, the germinations started to decrease after 2100 volts with a decrease to four percent at 2500 volts. Germinations of one percent are shown at 2700 and 2900 volts.

In figure 13, the germination of field bindweed is plotted against eight different plate voltages and for four different time periods.

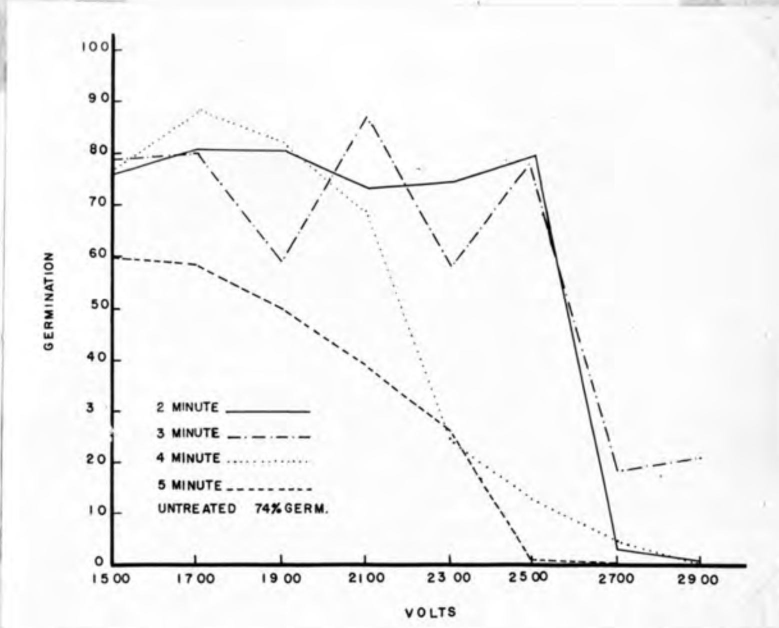

Fig. 13. The germination of field bindweed shown at eight different radio frequency plate voltages and for four different time periods.

The germination of field bindweed during the two minute time period from 1500 to 2500 plate volts shows no great variation. At 2700 volts there is a large decrease in germination from 80 percent at 2500 volts to three percent at 2700 volts. 2900 volts showed a one percent germination. Germination during the three minute time period show considerable variation and no distinct trend until after 2500 volts. During the four minute time period, the germination began to decrease after 1700 volts and continued to decrease with the higher voltages. The seed was devitalized at 2900 volts. The germination readings for the five minute time period were all lower than the readings for the two, three and four minute time periods.

The germinations, when treating quackgrass at eight different plate voltages and for four different time periods with radio frequency treatments, are found in figure 14.

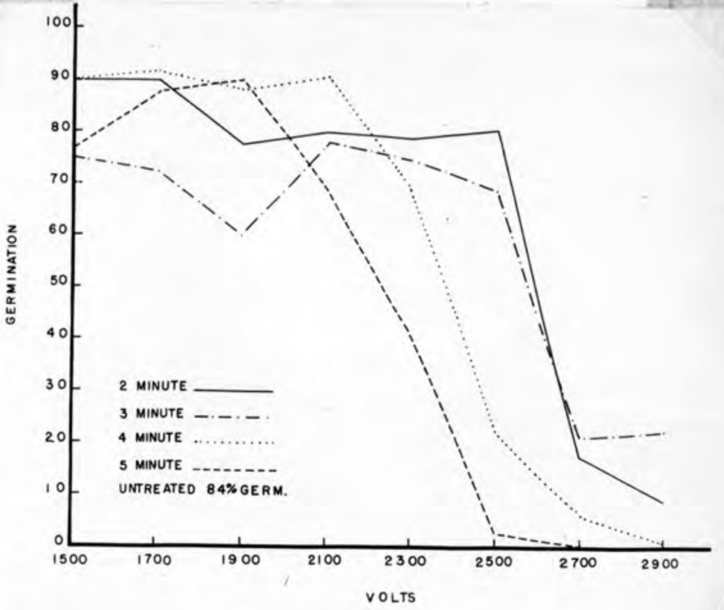

Fig. 14. The germination of quackgrass shown at eight different radio frequency plate voltages and for four different time periods.

During the two minute time period, a slight decrease in germination was noted at 1700 plate volts with a large decrease at 2500 volts. With the three minute time period, a constant decrease occurred after 2100 volts with a gradual decrease at 2500 volts and a sharp decrease at 2700 volts. During the four minute time period, the germinations decreased at the last four voltages with a germination of one percent at 2900 volts. The five minute time period shows a decrease in germination starting at 2100 volts. The germination was three percent at 2500 volts and devitalization occurred at 2700 volts.

The germination of perennial peppergrass, at eight different plate voltages and four different time periods is shown in figure 15.

The two minute time period germinations showed no consistent trend until after 2300 plate volts. A sharp decrease is noted at 2500 volts which continued to a zero percent germination at 2700 volts. A one percent germination is recorded at 2900 volts. The three minute time period showed the same trend in germination as the two minute time period with a definite decrease occurring after 2300 volts. A decrease in germination at one

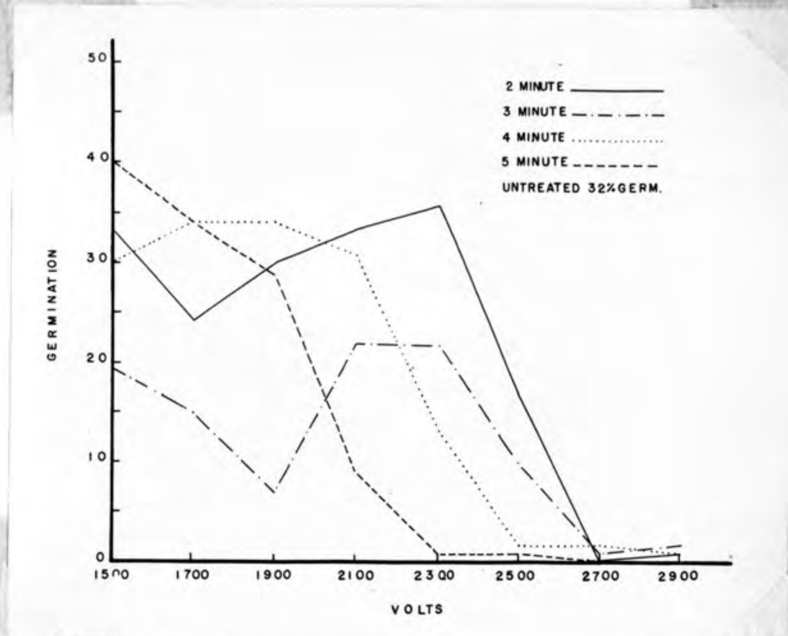

Fig. 15. The germination of perennial peppergrass shown at eight different radio frequency plate voltages and for four different time periods.

percent was reached at 2700 volts but there was a two percent germination at 2900 volts. At the four minute time period a small decrease in germination occurred at 2100 volts and a large decrease at 2300 and 2500 volts was noted. Germinations were two and one percent respectively for the 2700 and 2900 volt readings. At the five minute time period, germination started at 40 percent at 1500 volts, decreased to 28 percent at 1900 volts, nine percent at 2100 volts and the seed was devitalized at 2700 volts.

Figure 16 of leafy spurge shows the germinations at eight different plate voltages and at four different time periods.

The two minute time period germinations had a steady decrease in germination after 2100 plate volts to one percent germination at 2700 volts. The germination at 2900 volts was three percent. During the three minute time period, the decrease again occurred after 2100 volts. A steady decrease is noted from 2300 volts to 2900 volts. The four minute time period had a decrease in germination after 1900 volts. The decrease in germination

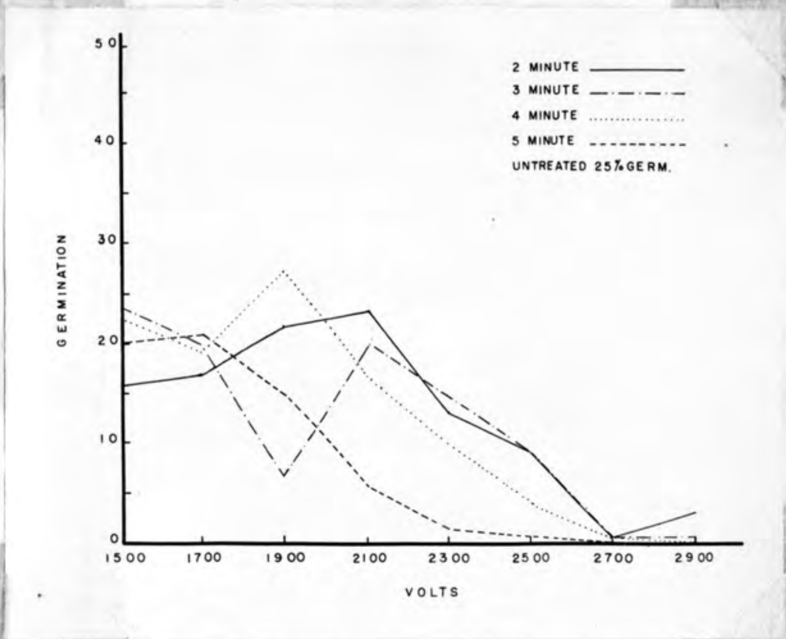

Fig. 16. The germination of leafy spurge shown at eight different radio frequency plate voltages and for four different time periods.

continued from 2100 volts to 2900 volts where devitalization was complete. The germinations at the five minute time period decreased after 1700 volts with every increase in voltage. The seed was devitalized at 2700 volts.

Figure 17 shows the germination of wild mustard at eight different plate voltages and at four different time periods.

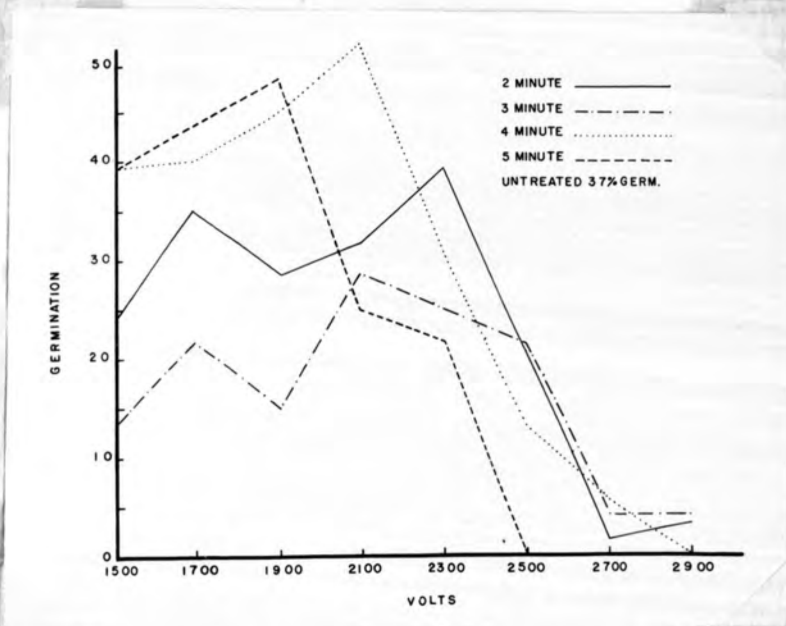

Fig. 17. The germination of wild mustard shown at eight different radio frequency plate voltages and for four different time periods.

The germination at the two and three minute time periods tend to follow the same trend throughout the eight plate voltages. Wide germination variations were encountered in the voltages up to 2300 volts. A constant decrease in germination was apparent at the two minute time period after 2300 volts and at the three minute period the decrease was noticeable after 2100 volts. The germination for the two minute time period at 2900 volts was three percent. The germination at 2900 volts for three minute time period was four percent. At the four minute time period, the germination decreased after 2100 volts, and continued until devitalization occurred at 2900 volts. The five minute period shows the same trend as the four minute time period. The decrease started at 2100 volts and the devitalization occurred at 2500 volts.

The germination of Canada thistle at eight different plate voltages and four different time periods is shown in figure 18.

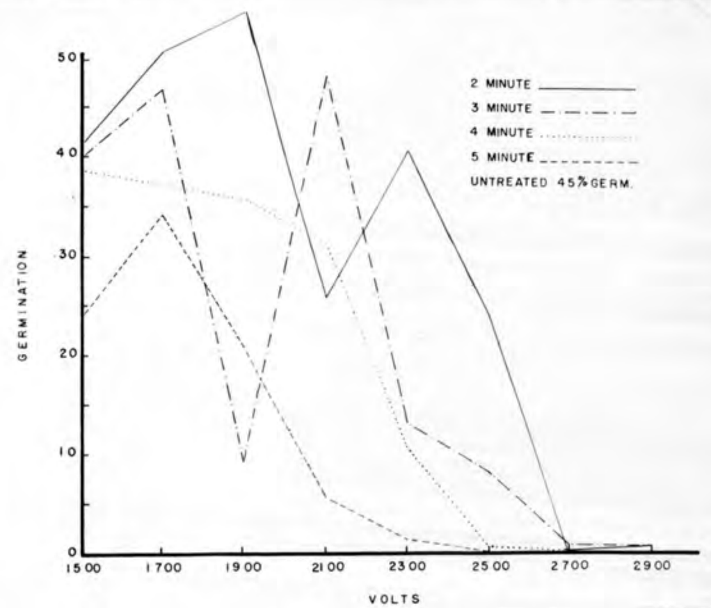

Fig. 18. The germination of Canada thistle shown at eight different radio frequency plate voltages and for four different time periods.

The two minute time period germinations gave no constant decrease until after 2300 plate volts. Devitalization of seed occurred at 2700 volts, but the 2900 volt test had one percent germination. The decrease in the germination, at the three minute time period first occurred after

2100 volts, and continued to one percent for both 2700 and 2900 volts. A decrease starting at 1500 volts is noted for the germinations during the four minute time period. Devitalization of seed occurred at 2700 volts. At the five minute time period, a decrease in germination began after 1700 volts. The decrease continued until devitalization of the Canada thistle seed occurred at 2500 volts.

Hard Seeds in Field Bindweed

Field bindweed was the only species in this test in which hard seeds were encountered. The percent of hard seeds at the eight plate voltages and the four time periods is shown in table 6.

Table 6. The percent of hard seeds of field bindweed when treated at eight different plate voltages and for four different time periods.

Time Exposed	Percent of hard seeds								
	Voltage								
	1500	1700	1900	2100	2300	2500	2700	2900	Untreated
Two minutes	78	82	76	84	84	88	90	82	86
Three minutes	82	90	64	82	70	72	60	68	88
Four minutes	84	88	74	58	60	70	58	56	94
Five minutes	84	78	72	64	56	54	56	50	94

Hard seeds in field bindweed were not affected when exposed for two minutes in the generator. During the three, four, and five minute time periods, a reduction in the percent of hard seeds accompanies the increase in plate voltage. The percent of hard seeds decreased at 2300 volts as the time periods increased. This was also true at 2500, 2700, and 2900 volts. The percent of hard seeds of field bindweed when exposed to 2900 volts for five minutes is reduced to nearly half of the percent of hard seeds found in the untreated sample.

DISCUSSION

Death from heat has been attributed to diverse effects, among them; 1) coagulation of protein components of protoplasm; 2) changes in the physical state of lipids; and 3) destruction or inactivation of enzymes. At present, the theory concerned with coagulation of protein components of protoplasm seems to be mostly generally accepted. Smith (6), however, has presented data which do not appear to substantiate the hypothesis that the killing effect is due simply to coagulation of protoplasmic proteins.

Cause of death after the seeds had been placed between the electrodes of the radio frequency generator appeared to be from heat. How high the temperature rose during these tests is not known. During one trial at a low plate voltage and for a short period of time an attempt was made to measure the temperature. A thermocouple was used in the attempt to determine the amount of heat produced by the generator. It was found that arcing between the electrodes of the generator was caused by the presence of the prong of the thermocouple. A temperature of 100 degrees C. was obtained when this arcing took place. Whether the temperature reading obtained was the true temperature of the seeds or was in error due to the presence of the thermocouple could not be determined. A thermometer was not used because it would be heated by the radio frequency field and would not read the temperature of the sample itself.

Any physical changes the seeds made during the treatment were carefully observed. There was considerable swelling of the seed at the higher plate voltages. This was noticed especially in the cereals. The swelling was somewhat like that which occurs when grain is soaked in water. In swelling, the seeds in the tube container pushed up the top electrode of the generator. At the end of the tests the seeds were usually damp. Excess moisture was present on the inside of the container and on the electrodes. The swelling and accumulation of moisture seem to be associated with the higher plate voltages.

There appeared to be very little difference between the cereal and the weed seeds used, as to the amount of treatment they could withstand.

When the germination of Canada thistle is compared with wheat, it was found that at the two minute time period of from 1500 to 2500 plate volts no significant trend in the germination was observed. At 2500 volts wheat germination was reduced by one-half. At 2700 volts, Canada thistle seed was completely killed while wheat still germinated 10 percent. At the three minute time period with 2300 volts, wheat germinated 88 percent and Canada thistle only 13 percent. It was found that wheat was reduced in germination six percent while Canada thistle by the same treatment was reduced 71 percent. The same wide differences in the germination of these two kinds of seeds were observed in the other time periods and voltages. Treatments that greatly reduced Canada thistle germination also reduced wheat germination although not in a corresponding percentage. However, treatments that devitalized Canada thistle also reduced the germination of wheat to the extent it could hardly be considered suitable for plant purposes.

During the two and three minute time periods, germination of all seeds remained consistently high until 2700 and 2900 plate volts were applied. At these voltages a sudden drop in germination occurred. A pronounced decrease in germination was obtained at 2500 volts at the four minute exposure period. During the five minute time period, the pronounced decrease was noticed first at 2300 volts and continued into 2500 volts where the germination was decreased to practically zero. The results obtained in the four and five minute time periods appear to substantiate the possibility that the amount of heat generated increased until it reached the maximum that seeds will stand before rapidly becoming devitalized.

Throughout the tests wild oats remained the highest in germination at the high plate voltages. It was also noted, that in nearly all cases, high germinations of wild oats were recorded when all other germinations had started the first noticeable decreases.

Oats tended to follow the same trend as wild oats, only in a lesser degree. This may indicate that the glumes surrounding the wild oats and oats caryopses afforded some protection against devitalization. On the other hand, the hard seed coat of field bindweed did not seem to alter the devitalization of that seed and apparently offered no protection against the treatments. This is shown by the results of the 2900 plate volt five minute time period. The hard seed content was reduced to nearly one-half of the untreated sample, but upon scarification these hard seeds were found to be devitalized.

No tests for possible loss or change in feeding value were made on cereals after treatment. If complete devitalization was obtained, the weed seeds would not be a factor in the spread of weeds when the devitalized grain was used for feeding purposes.

SUMMARY

1. Wheat, oats, and barley were used as the cereals in this test. All were devitalized at 2700 and 2900 plate volts at the five minute time period. Of the weed seeds used, field bindweed, perennial peppergrass, leafy spurge, wild mustard, Canada thistle, and quackgrass were devitalized at 2700 and 2900 plate volts at the five minute time period.

2. Wild oats was the only weed seed not devitalized at any of the plate voltages or time periods. The germination however, was reduced to one percent at 2700 and 2900 plate volts at the five minute time period.

3. There appeared to be but very little difference between the amount of treatment needed to devitalize weed seed and that needed for cereals.

4. Germinations were reduced by increasing the plate voltage applied to the generator tube. Germinations were reduced also at lower plate voltages by increasing the time periods.

5. Canada thistle was the most sensitive to the treatment of any of the seed tested.

6. Devitalization of weed seed also reduced the germination of cereals to the extent that they were not suitable for seeding purposes.

7. Heat was probably the factor which caused the devitalization of the cereal and weed seed. The temperatures were not determined because difficulty was encountered in their measurement.

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